Australian Government
Department of Defence
Defence Science and
Technology Organisation

Dec 2003

DSTO

Photonic Radio Frequency Memory - Design Issues and Possible Solutions

Linh V. T. Nguyen

DSTO-TR-1491

Australian Government
Department of Defence
Defence Science and
Technology Organisation

Photonic Radio Frequency Memory – Design Issues and Possible Solutions

Linh V T Nguyen

Electronic Warfare & Radar Division
Systems Sciences Laboratory

DSTO-TR-1491

ABSTRACT

False target generation, range and velocity gate pull-off are Electronic Attack (EA) techniques in which received radar pulses are stored, then read out and re-transmitted back to the source radar after the desired length of time. The memory can be either a recirculating delay line or a digital radio-frequency (RF) memory (DRFM). The DRFM stores a digitised sample of each received pulse, which can provide high fidelity if the analogue-digital conversion process has sufficient dynamic range. The speed of digital signal processing and memory plays a critical role in DRFM design. The analogue-digital conversion process and bit-rate limit the range of frequencies that DRFMs can cover.

Photonics is currently being investigated to implement EA techniques such as false target generation, range and velocity gate pull-off. To fully take advantage of the unique benefits offered by photonics to implement EA techniques, the development of photonic RF memory (PRFM) is required. PRFM can potentially cover frequencies from near DC to 110 GHz, which are of interest in Electronic Warfare (EW). Photonic technology offers the opportunity for high fidelity signal storage without the use of down-conversion or analogue-to-digital converters. In this report, design issues and possible solutions of PRFM are discussed to assist with the ongoing experimental investigation.

Published by

DSTO Systems Sciences Laboratory
PO Box 1500
Edinburgh South Australia 5111 Australia

Telephone: (08) 8259 5555
Fax: (08) 8259 6567

AR-012-890
September 2003

Photonic Radio Frequency Memory – Design Issues and Possible Solutions

Executive Summary

Photonic technology is characterised by low in-fibre attenuation, wide bandwidth and immunity to electrical interference. These characteristics make photonics ideal for the manipulation of radio frequency (RF), microwave and millimetre-wave signals. In particular, photonics has been proposed as an enabling technology for Electronic Warfare (EW) applications. Electronic Attack (EA) techniques such as false target generation and range and velocity gate pull-off require storage of received radar pulses. If photonic EA techniques are to be practical, then photonic RF memory (PRFM) is required. Photonic technology offers the potential for high fidelity signal storage without the use of down-conversion or analogue-to-digital converters.

Photonic memories based on fibre-optic true-time delays are practical. Fibre-optic delays have been used for beamforming of phased-array radar systems and in a simple *microwave photonic jammer*. Fibre-optic active recirculating loops have been used to simulate long-haul telecommunication systems and have been proposed as input buffers for packet-switched data. The development of photonic memories for EA techniques based on passive fibre-optic delays and active recirculating loops requires customisation to meet EA system specifications.

Design concepts for photonic memory based on passive fibre-optic delays are simple. Passive and switchable PRFM requires optical switches that are characterised by fast switching speeds and low insertion losses. However, designing PRFM based on the active recirculating loop is complex because it utilises an optical amplifier to compensate for the loop attenuation in order to maintain a constant optical power level. Critical design issues of the active recirculating loop are noise accumulation and automatic loop-gain control.

Noise accumulation in the recirculating-loop PRFM must be clarified into two distinct forms, known as *homodyne* and *heterodyne* sources. Homodyne noise cannot be filtered out, while the heterodyne noise can be minimised by a combination of optical bandpass and time-domain filtering. Time-domain filtering is often referred to as *gating*. In addition, when dense wavelength-division multiplexing (DWDM) is used to enhance the functionality of the recirculating-loop PRFM, then optical powers at various wavelengths require simultaneous equalisation; a result of optical amplifiers not having perfectly flat gain responses. Consequently, the automatic loop-gain control problem becomes multi-variable involving both optical power and wavelength.

In this report, design issues of PRFM are analysed and discussed to understand its limitations. Possible solutions to overcome various design issues are suggested to assist the ongoing experimental investigation of PRFM within the Electronic Warfare and Radar Division.

Authors

Linh V T Nguyen
Electronic Warfare & Radar Division

Linh Nguyen received the BSc in 1992 and BE (EEE) in 1993 from the University of Adelaide, and PhD in 1997 from the Photonics Research Laboratory, Australian Photonics Cooperative Research Centre, Department of Electrical & Electronic Engineering, University of Melbourne.

He has held positions at the Photonics Research Laboratory, Vicom Australia Pty. Limited and Acterna Asia-Pacific Pty. Limited. He has also completed a Master of Marketing at the Melbourne Business School. He currently holds a Research Scientist position in the Electronic Warfare & Radar Division, DSTO Edinburgh, where his research interests are in the field of microwave photonic signal processing and its applications to Electronic Warfare. He is the Task Manager for Photonic Systems Technology in the Electronic Warfare & Radar Division.

Contents

1. Introduction

The application of photonic technology to implement Electronic Warfare (EW) solutions is an ongoing effort within the Electronic Warfare & Radar Division, Defence Science and Technology Organisation. Much of the effort to-date has been concentrated on Electronic Support (ES) [1-2]. Electronic Attack (EA) has received limited attention [3]. EA techniques such as false target generation and range and velocity gate pull-off require storage of received radar pulses.

The *memory* can be either a recirculating delay line or a digital radio-frequency (RF) memory (DRFM). The DRFM stores a digitised sample of each received pulse, which can provide high fidelity if the analogue-digital conversion process has sufficient dynamic range. The speed of real-time digital signal processing and memory plays a critical role in DRFM design. The analogue-digital conversion process and bit-rate determine the range of frequencies that DRFMs can cover. Photonic RF memory concepts can potentially operate for all frequencies from near DC to 110 GHz, which are of interest in Electronic Warfare (EW). Photonic technology offers the opportunity for high fidelity signal storage without the use of down-conversion or analogue-to-digital converters [3].

In particular, the active recirculating loop was investigated as a form of PRFM. For optimum resolution, the delay length of the loop should be in the same order as the received radar pulsewidth, which may range from a fraction of a microsecond to several milliseconds [4]. The purpose of the recirculating-loop PRFM is to replay the received radar pulses continuously, so that each of the replayed pulses can be selected and processed for false target generation, range and velocity gate pull-off [3-4].

The barriers to a successful research outcome, as described by Reference 3, were mainly noise accumulation and degrading pulse power after recirculation due to the difficulty in controlling the closed-loop gain close to unity [3]. Figure 1 depicts up to 45 recirculations with decreasing pulse amplitude [3]. However, it is unclear as to how many of these recirculations could be used in a microwave photonic jammer due to the decreasing pulse amplitude.

It has been illustrated recently, by numerical simulation, that the non-ideal extinction ratio from the input electro-optic modulator (EOM) is a critical factor limiting the performance of the active recirculating loop [5]. This poor extinction ratio is the major source of homodyne noise. The other noise source, both homodyne and heterodyne, is the amplified spontaneous emission from the optical amplifier.

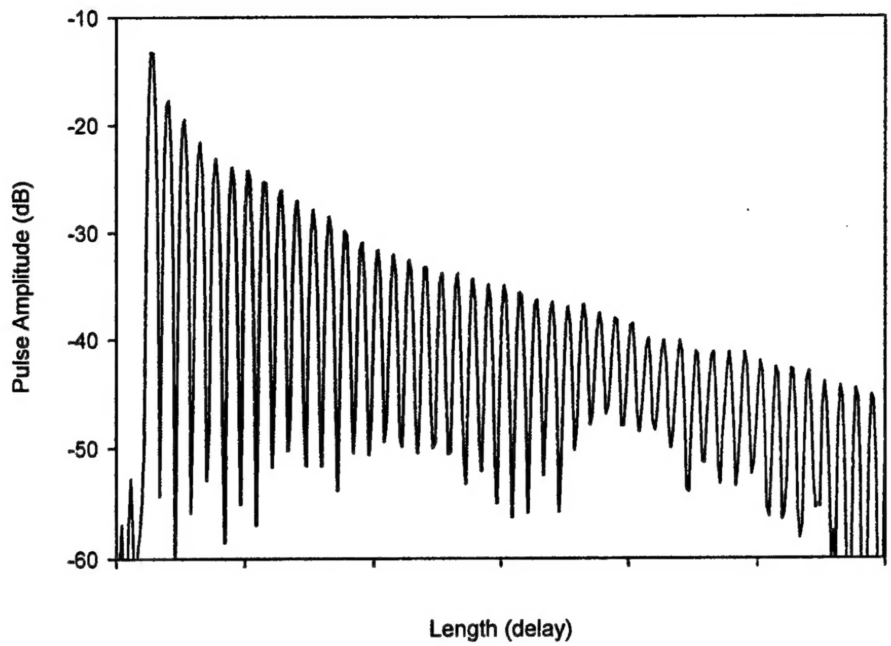


Figure 1: Loop recirculations for 1-km delay [3].

Extensive investigation into the application of the active recirculating loops as photonic memory for packet-switched data has been performed, e.g. [6]. Data recirculation was achieved in a loop comprising of 80 metres of standard non-polarisation-maintaining fibre (equivalent to 443 nsec), using a semiconductor optical amplifier (SOA) as the active element and high-speed lithium niobate ($LiNbO_3$) optical switches. The design reported in Reference 6 is directly comparable to the architecture suitable for PRFM in terms of loop delay and number of recirculations. The performance of the active recirculating loop in Reference 6 was thoroughly analysed and its findings have direct implication to the application of the active recirculating loop as PRFM.

In this report, a technical review of both passive-switchable and active recirculating loop architectures of PRFM will be presented. Discussions on design complexity and operational difficulties will be highlighted. Solutions will be proposed using the latest commercial-of-the-shelf (COTS) photonic technology where possible. If a solution is not readily available, a research proposal will be recommended. The purpose of the report is to assist the ongoing experimental investigation into PRFM being undertaken within the Electronic Warfare & Radar Division.

The structure of this report is arranged into the following sections:

- *Passive-Switchable Photonic RF Memory* section outlines preferred designs of simple switchable fibre-optic memory for EA applications.
- *Recirculating-Loop Photonic RF Memory* section presents design issues and possible solutions relating to the photonic active recirculating loop.
- *Conclusions* summarise the findings of this report.
- *Recommendations* detail future research directions.

2. Passive-Switchable Photonic RF Memory

Passive-switchable photonic memories for Electronic Attack (EA) applications are easier to implement than active recirculating loops. The primary problem associated with the passive-switchable photonic memory is the availability of optical switching technology that is characterised by both fast switching speed and low insertion loss.

2.1 Switchable Fixed-Delay Memory

A simple passive-switchable photonic memory with fixed delays is shown in Figure 2 [4]. This design requires a pre-determined set of optical true-time delays to be used, τ_N, which can be selected by using the two optical switches. The total insertion loss of the memory in Figure 2 is simply that of the two optical switches. The $N \times 1$ optical switch can be replaced with an optical combiner, which are less expensive than optical switches. However, commercial-off-the-shelf (COTS) optical combiners exhibit high insertion loss because they are actually optical splitters, i.e. their insertion loss is $\log_2(N) \times 3\,\text{dB}$ where N is rounded up to the nearest power of 2. The photonic memory design illustrated in Figure 2 would have limited practicality in EA [4], but it is useful for radar range calibration applications.

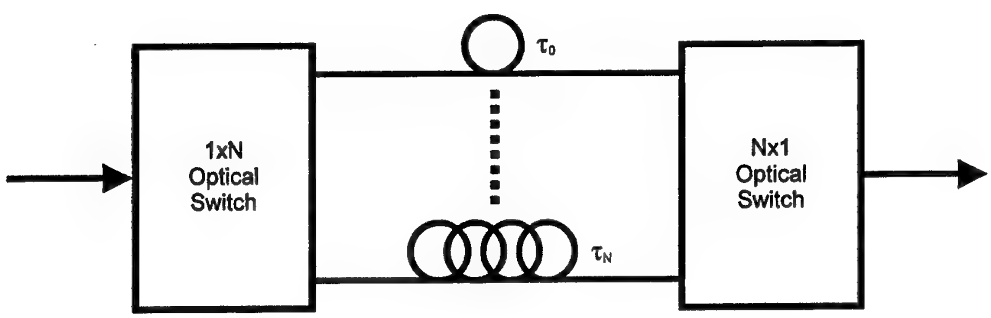


Figure 2: A switchable fixed-delay photonic memory [4].

2.2 Switchable Binary Delay Memory

A switchable binary delay photonic memory is more practical than fixed-delay design for false target generation and range gate pull-off [4]. The architecture of such a memory design is shown in Figure 3. It consists mostly of 2×2 optical switches, fibre-optic true-time delays and an optical coupler. The maximum delay achievable depends on the number of optical switches used in the design. The variable storage time has a resolution equal to the smallest delay, τ. Note that if $\tau_i = 2^i \tau_0$ in Figure 2, then it is equivalent to the architecture in Figure 3.

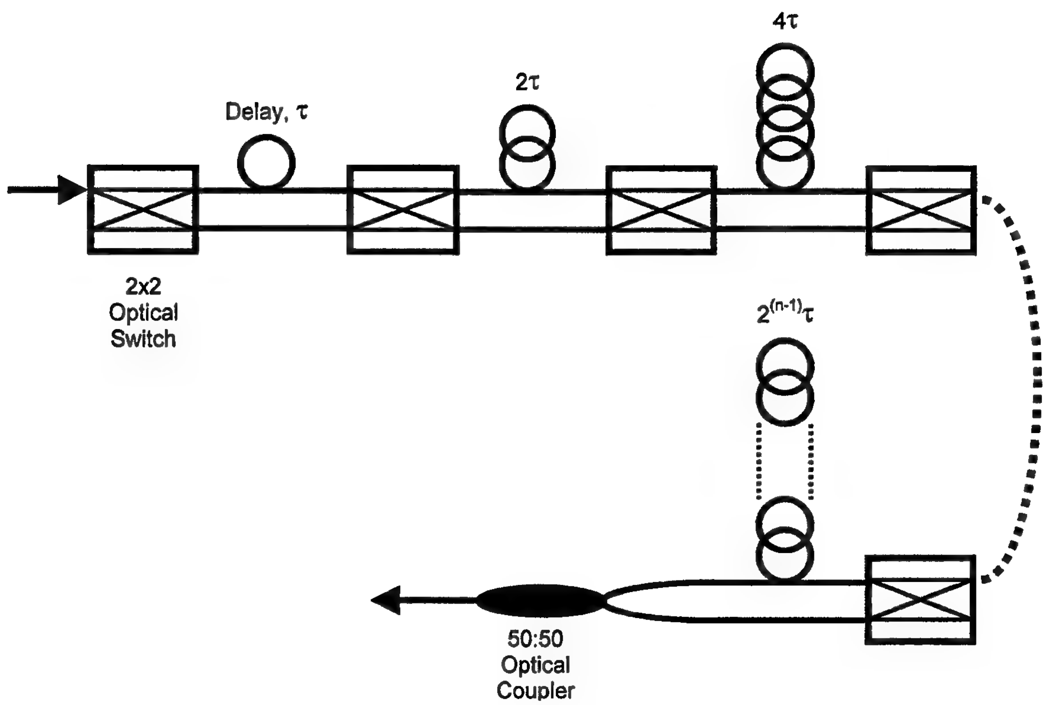


Figure 3: A switchable binary delay photonic memory [4].

The maximum storage time of the PRFM shown in Figure 3 can be shown using the principle of induction to be:

$$T_{max} = \left(2^n - 1\right)\tau \qquad (1)$$

where n is the number of optical switches used in the memory architecture. Let the insertion loss in dB of each optical switch be, L_{OS}, then total insertion loss of the architecture shown in Figure 3 is:

$$L_{total} = nL_{OS} + 3\,\text{dB} \qquad (2)$$

This is the loss experienced by an optical signal propagating through the memory architecture when n switches are used, regardless of the actual delay required. The attenuation in optical fibres is negligible for short fibre lengths in comparison to the total insertion loss of all the optical switches. When n is large, optical amplification is necessary to compensate for signal attenuation.

2.3 Discussion

The passive-switchable binary delay photonic memory is currently being investigated experimentally in the Electronic Warfare and Radar Division [7]. The performance of optical switches is critical to both types of passive-switchable photonic memories illustrated in Figures 2 and 3. The timescale required to rearrange the switches to select the optical storage time must be minimised so that real-time countermeasure techniques can be initiated at the earliest possible instance. In addition, the switches must have low crosstalk to avoid multiple-path interference corrupting the stored radar pulse.

Examples of four types of COTS optical switches and their respective typical parameters are listed in Table 1:

Table 1: Commercial-off-the-shelf optical switch technologies.

Type	Insertion Loss	Switching Speed	Crosstalk	Reference
Prism or optomechanical	<1 dB	Millisecond	<-80 dB	Dicon Fiberoptics Inc. [8]
Lithium niobate ($LiNbO_3$)	~4.5 dB	Nanosecond	~20 dB in extinction ratio	Aeroflex Microelectronic Solutions [9]
Thermo optic	<2 dB	Millisecond	~20 dB in extinction ratio	Zenastra Photonics Inc. [10]
Optical MEMS	<1 dB	Fraction of a millisecond	<-55 dB	JDS Uniphase [11]

There is no single technology that offers both fast switching speed and low insertion loss. Lithium niobate ($LiNbO_3$) technology offers nanosecond-switching speed, but it has high insertion loss and poor extinction ratio. Prism switches offer the lowest insertion loss and low crosstalk, but their switching speed is slow. Optical micro-electrical-mechanical system (MEMS) offers performance in between $LiNbO_3$ and prism technologies.

Millisecond switching speed is perfectly applicable to telecommunication network protection switching, which is the main commercial market for these devices. However, millisecond switching would be slow for EA applications. When used in PRFM for EA techniques, detected pulses from hostile threats are required to be switched into the memory at a fraction of the pulsewidth to ensure that real-time deceptive countermeasures can be employed at the earliest possible instance for maximum effect. In environment where hostile threats have long pulse repetition interval (PRI), during which the optical switches could be configured, then simple jamming techniques could be employed. Ideally, a switching technology that possesses the following performance would be an excellent candidate for passive-switchable photonic memory:

1. Nanosecond switching speed,

2. Low insertion loss, and
3. Low crosstalk, i.e. high extinction ratio.

No single COTS optical switching technology listed in Table 1 has this desirable combination of characteristics. Therefore, design trade-offs for passive-switchable PRFM based on COTS optical switches are necessary. These trade-offs will be dependent on the specific application of the memory.

One technology that exhibits near-ideal characteristics is an all-optical switching solution known as a nonlinear optical loop mirror (NOLM) [12]. This all-optical switching action is based on nonlinearities in optical fibres. The one disadvantage of this solution is the high optical power level (>+20 dBm) required to activate switching behaviour [12]. There are specialty optical fibres with high levels of nonlinearities [12], which would reduce the necessary optical power required to activate switching behaviour.

Photonic storage based on passive-switchable PRFM does not incorporate any form of signal regeneration. The stored radar pulse propagating through the optical true-time delays can only be replayed once, and then the delay network has to be re-arranged for a new delay value. However, the PRFM based on an active recirculating loop has the capability to replay the pulse continuously during the PRI allowing for fine delay resolution without the penalty of slow optical switching speed. In addition, the versatility and flexibility of the recirculating-loop PRFM to be adapted and operated under different threat environments are advantageous.

3. Recirculating-Loop Photonic RF Memory

A fibre-optic active recirculating loop had been demonstrated as photonic memory [6]. In theory, there is no reason why the recirculating loop cannot be used as photonic radio-frequency (RF) memory (PRFM). In this section, analysis is carried out to determine critical design issues needing to be addressed to enable the active recirculating loop to be operated as PRFM.

3.1 Recirculating-Loop PRFM Architecture

The recirculating-loop PRFM of interest for Electronic Attack (EA) applications is as illustrated in Figure 4. It consists of three stages:

1. Input stage - A laser diode and an external electro-optic modulator (EOM). A suitable modulation scheme will be analysed later in this section.
2. Memory stage - An active recirculating loop. A suitable optical amplifier technology will be discussed later in this section. The choice of optical coupling ratio will influence the magnitude of optical gain required.
3. Output stage - A high-speed optical switch to select the replayed pulses. The isolator blocks any back-reflection from the switch back into the loop. This stage is simple and has little influence on the operation of the previous two stages.

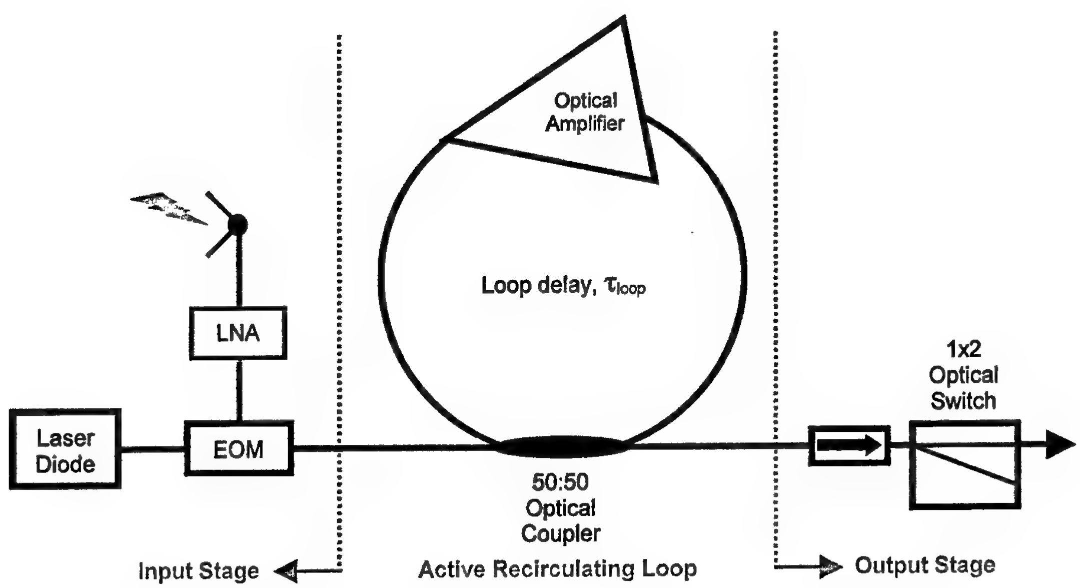


Figure 4: A basic architecture of a recirculating-loop PRFM.

The active recirculating loop shown in Figure 4 is similar to that reported in Reference 6. There is an additional optical switch at the input to the active recirculating loop in Reference 6, which was used to direct packet-switched data either to the input buffer, waiting for the busy packet processor, or directly to the processor. The loop delay used in Reference 6 is around 443 nsec, which is at the narrow end of radar pulsewidth range [4]. This makes the research by Adam Dickson [6] the best authority for recirculating-loop PRFM in comparison to recirculating loops simulating long-haul telecommunication systems.

3.2 Representative Model of Active Recirculating Loop

A simple model of the optical field recirculating in the loop is required to investigate how the performance of the input stage can influence the storage performance of the loop. The optical frequency at 1550 nm is equivalent to 193 THz. If the actual loop delay, ranging from microseconds to millisecond, were simulated, then the numerical computation would become too intensive and inefficient due to the high sampling rate of the optical field.

A representative model of the active recirculating loop was developed by scaling down the optical frequency to 200 GHz, referred to as f in the model. This is practically the same as the under-sampling process used in the Transmission-Line Laser Modelling technique [13] and photonic simulation software from VPIsystems [14]. The model is based on the ideal active recirculating loop as shown in Figure 5, with a noiseless optical amplifier having a gain of 2.

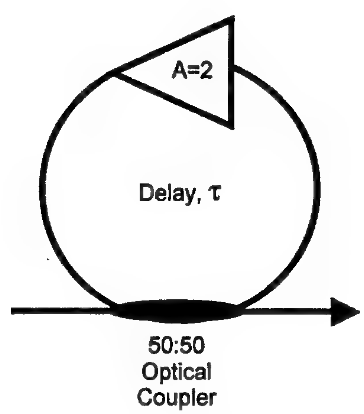


Figure 5: An ideal active recirculating loop.

Let the input continuous-wave (CW) optical field with unity amplitude be:

$$E_{in}(t) = \sin\left(2\pi\left[f + \frac{1}{2}\Delta f\, x_i\right]\right) \tag{3}$$

where Δf is the linewidth of the representative optical field and x_i is a Gaussian-distributed random variable in the interval $0 \le |x| < \infty$. The linewidth distribution of semiconductor lasers is Lorentzian [16], which can be approximated to a Gaussian distribution near the peak region. The Gaussian-distributed random variable is defined by the inverse error function of a uniform random variable $0 \le u \le 1$ [15]:

$$x = \pm\sqrt{2}\,\mathrm{erf}^{-1}(u) \qquad (4)$$

The output optical field of the ideal active recirculating loop is:

$$E_{out}(t) = \sqrt{\frac{1}{2}}E_{in}(t) + \sqrt{\frac{A}{2}}E_{out}(t-\tau) \qquad (5)$$

In fact, the active recirculating loop represented by Equation 5 is a microwave photonic filter if CW input is considered. The optical power at the output of the recirculating loop can be recorded as $|E_{out}(t)|^2$. In the representative model, a loop delay of 1 nsec is proposed to reduce the numerical computation significantly. The sampling of the representative optical field at 200 GHz is proposed at 2.4 THz, and the simulation is to be run over a total of 25 recirculations.

3.3 Simulation of Active Recirculating Loop

Simulations of the active recirculation loop were performed for both CW and pulsed optical input. This is to show that the simple input stage shown in Figure 4 would be inadequate without incorporating noise suppression.

3.3.1 CW Input

The input stage using a DC-biased EOM in Figure 4 produces a CW optical carrier. Electrical modulation occurs when radar pulses are received. A further advantage of simulating with CW input is that it also represents the inter-pulse interference expected if the radar pulsewidth is greater than the recirculating loop delay.

Figures 6 and 7 show the results for CW input with Δf equal to 1 MHz and 1 GHz, respectively. Figure 6 shows an exponentially increasing staircase output due to constructive interference. Meanwhile, the phase noise of the incoherent input having 1 GHz linewidth has been translated into intensity noise in Figure 7. The behaviour of noise accumulation in Figure 7 is exponential, but at a slower rate. Similarly, simulations were carried out with the loop delay increased by 2 timesteps to represent environmental fluctuations, i.e. fibre length or wavelength fluctuation [16]. Figure 8 shows the result of optical coherence interference with 1 MHz linewidth, while the incoherent input has insignificantly affected the output illustrated in Figure 9. The effects of fibre chromatic dispersion have not been modelled and must be considered.

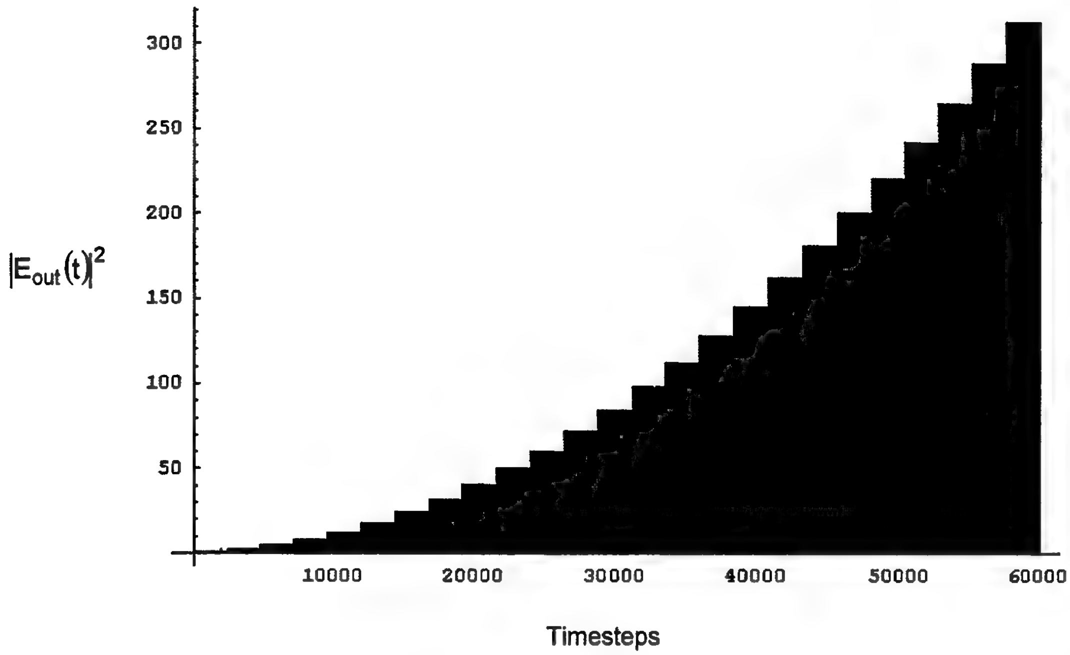


Figure 6: Output of representative loop model for CW input with linewidth of 1 MHz.

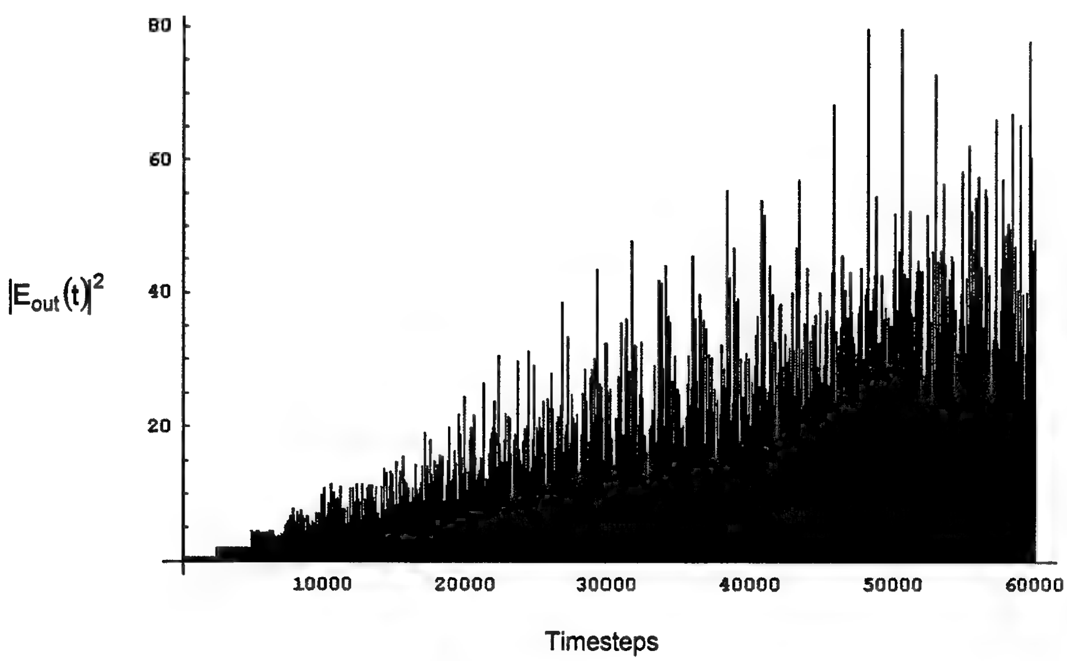


Figure 7: Output of representative loop model for CW input with linewidth of 1 GHz.

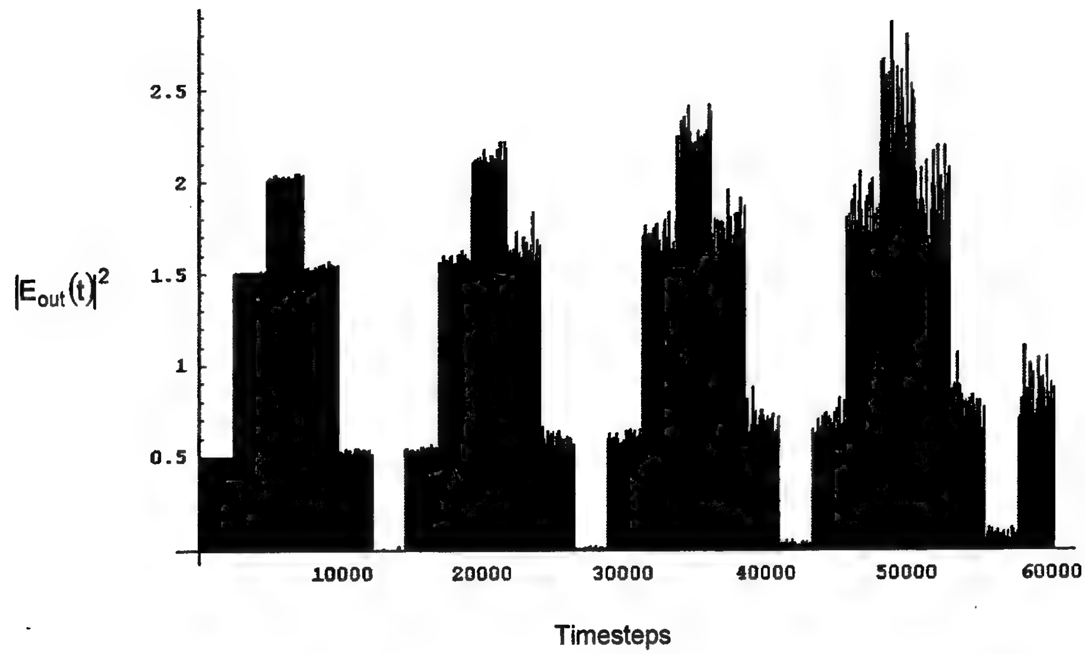


Figure 8: Output of model with 1 MHz linewidth and loop delay increased by 2 timesteps.

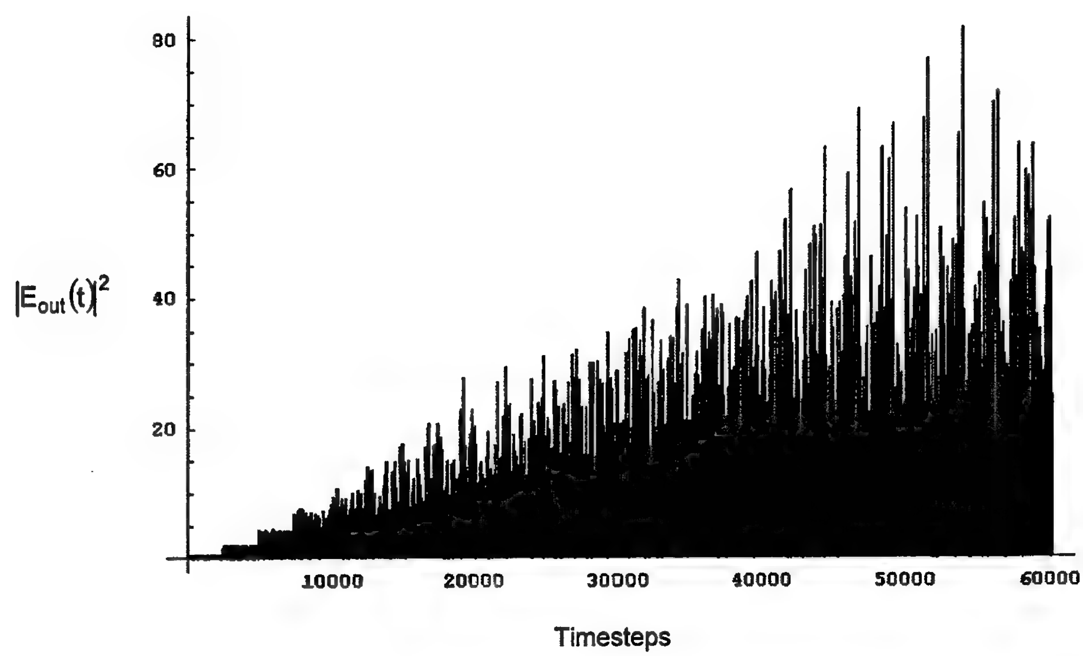


Figure 9: Output of model with 1 GHz linewidth and loop delay increased by 2 timesteps.

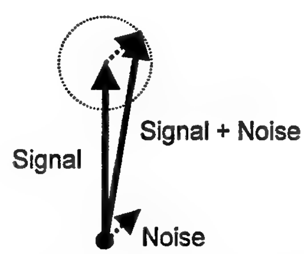
The simulation results illustrated in Figures 6 to 9 show that the CW input is not suitable for the active recirculating loop. The loop delay must always be greater than the width of the radar pulse to be stored to avoid inter-pulse interference. The disparity between the loop delay and radar pulsewidth will be discussed later when noise accumulation from the optical amplifier is considered.

3.3.2 Pulsed Input

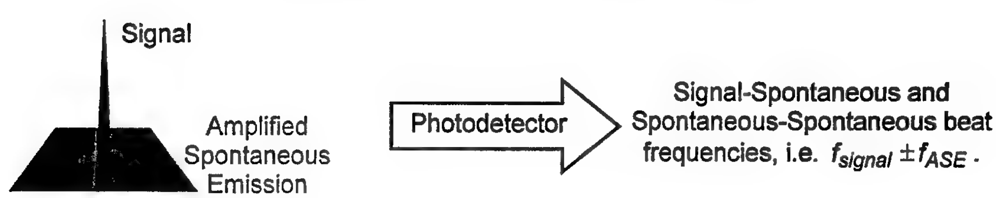
In the simulation, the pulsewidth is taken to be 200 timesteps less than the recirculating loop delay. The pulse modulation function of the input optical field takes the following form:

$$A(t) = \begin{cases} 1 \text{ for } 0 \le t \le \tau - 200\Delta t \\ \sqrt{\alpha} \text{ otherwise} \end{cases} \tag{6}$$

where τ is the recirculating loop length, Δt is the time step and α is the EOM extinction ratio. The non-ideal extinction of the pulse modulation is modelled accordingly. The EOM leakage is an input homodyne noise source, which has the same wavelength and interferes coherently with the recirculating pulse. It can only be suppressed, but cannot be filtered out. This is not the same as heterodyne noise produced at the photodetector. The concept of homodyne and heterodyne noise sources is illustrated in Figure 10.



(a) Vector representation of homodyne noise



(b) Heterodyne noise

Figure 10: Concept of homodyne and heterodyne noise sources.

The concept of homodyne noise can be understood by the vector addition of the signal of interest and noise at the same wavelength. The noise component could have any phase, i.e. $[0, 2\pi]$, with respect to the signal of interest. Therefore, the resultant vector would have amplitude fluctuation up to 2 times or 3 dB of the noise amplitude. In relation to the active recirculating loop, homodyne noise continually accumulates quickly in the active recirculating loop, corrupting the stored pulse.

Unlike homodyne noise, heterodyne noise is produced at the photodetector, where the signal of interest beats with the amplified spontaneous emission (ASE) at other wavelengths, resulting in electrical interference. The ASE also beats with itself, but the spontaneous-spontaneous product is often negligible in comparison to signal-spontaneous beat noise. Heterodyne noise can be suppressed by optical bandpass filtering the ASE.

Simulations were performed with a pulsed input optical carrier with a linewidth of 1 GHz and an ideal open-loop optical amplification of 2, as shown in Figure 5. Figures 11 to 13 show the recirculating output of the model for modulation extinction ratios of 20, 50 and 100 dB, respectively. The modulation leakage, due to imperfect extinction of the optical carrier through and into the recirculating loop, corrupts the recirculating or stored pulse, as illustrated in Figure 11. Improving modulation extinction suppresses the source of homodyne noise from the input and thereby improving pulse recirculation, as depicted in Figure 13. Figure 13 demonstrates consistency with an observation from Reference 5, that the poor EOM extinction ratio is a critical factor limiting the performance of the active recirculating loop. The same simulations were repeated with a linewidth of 1 MHz and the same observations resulted. It can be concluded that poor EOM extinction ratio allows the input homodyne noise into the recirculating loop to corrupt the stored pulse.

Figure 14 shows the same simulation as illustrated in Figure 11, but with a reduced open-loop gain of 1.85. The reduction of the open-loop gain suppresses the intensity noise at the output for the first several recirculations. However, it does not affect the accumulation of homodyne noise due to poor EOM extinction ratio. Since the closed-loop gain is now below unity, the recirculating pulse power decreases and would eventually converge to the same level as the accumulated homodyne noise. It is worth noting that practical optical amplifiers are noisy, unlike the ideal model, and will produce ASE further adding to the accumulation of homodyne and heterodyne noise.

The conclusion concerning the input homodyne noise source is consistent with published research [6,17]. Multiple lithium niobate ($LiNbO_3$) optical switches were recommended in Reference 6 to achieve high isolation of the input optical carrier and the packet-switched data in the recirculating loop. In Reference 17, a semiconductor optical amplifier (SOA) was used after the EOM to achieve a suitable performance of data storage.

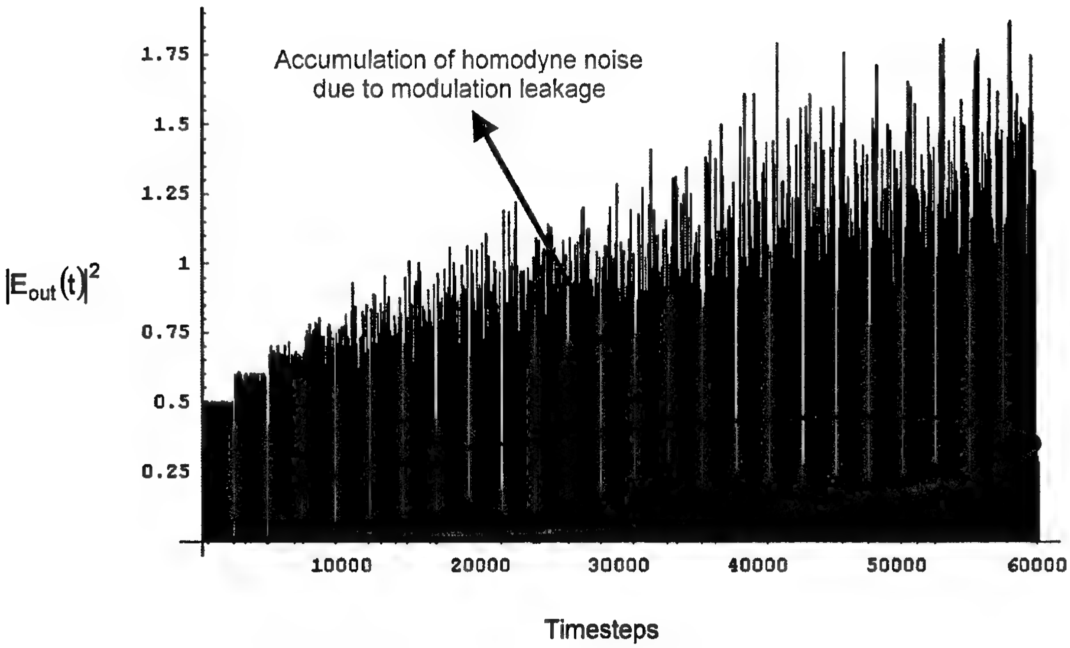


Figure 11: Output of model for pulsed input with 20 dB extinction ratio.

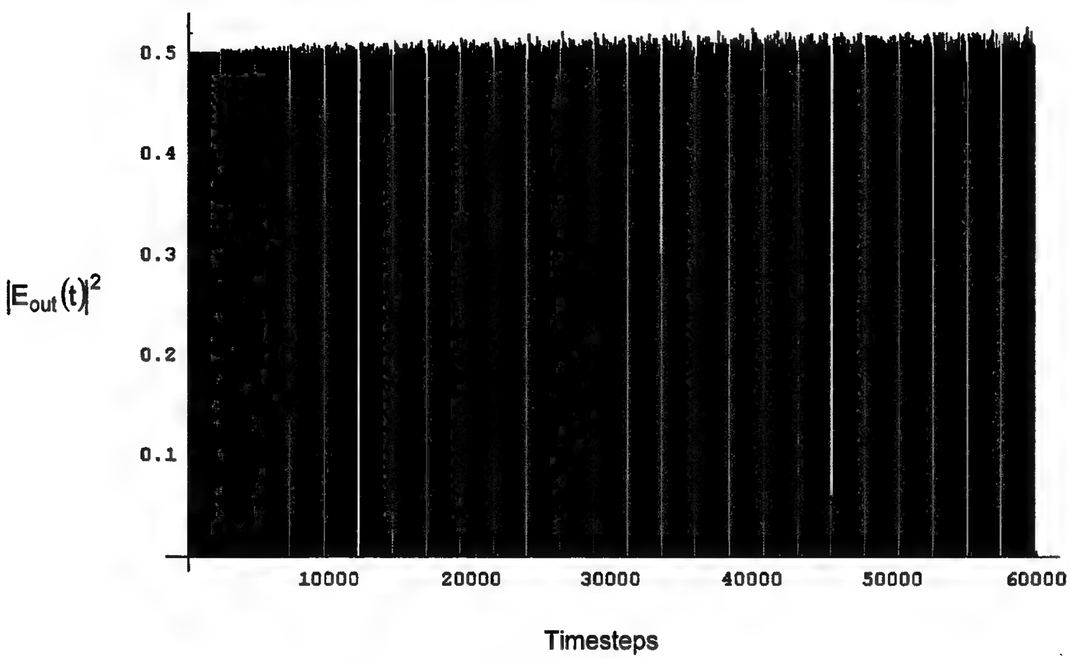


Figure 12: Output of model for pulsed input with 50 dB extinction ratio.

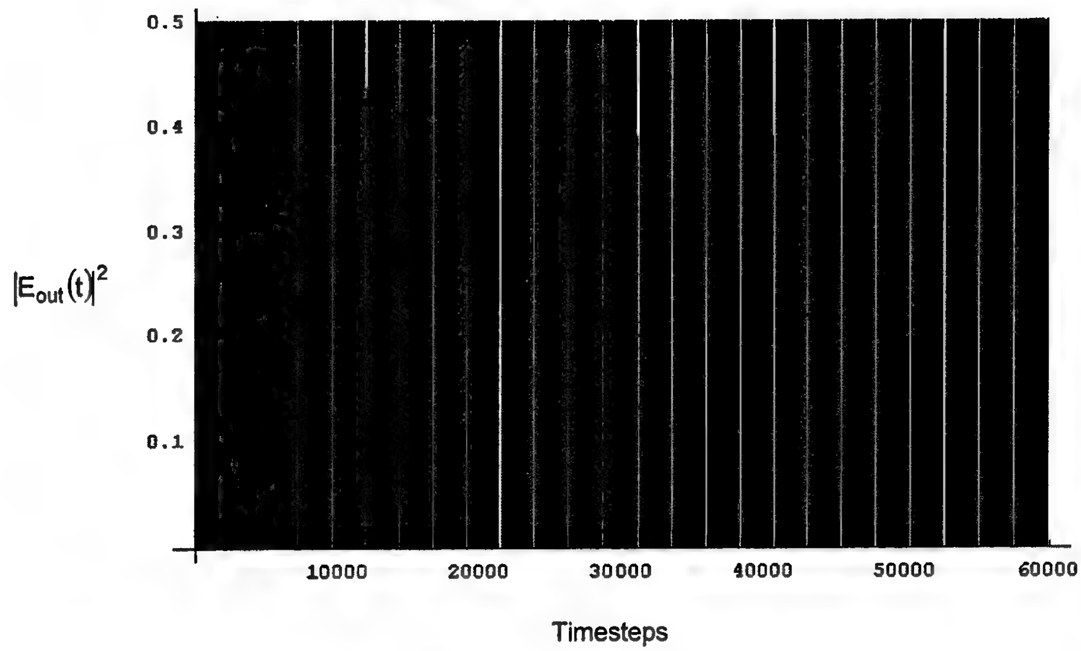


Figure 13: Output of model for pulsed input with 100 dB extinction ratio.

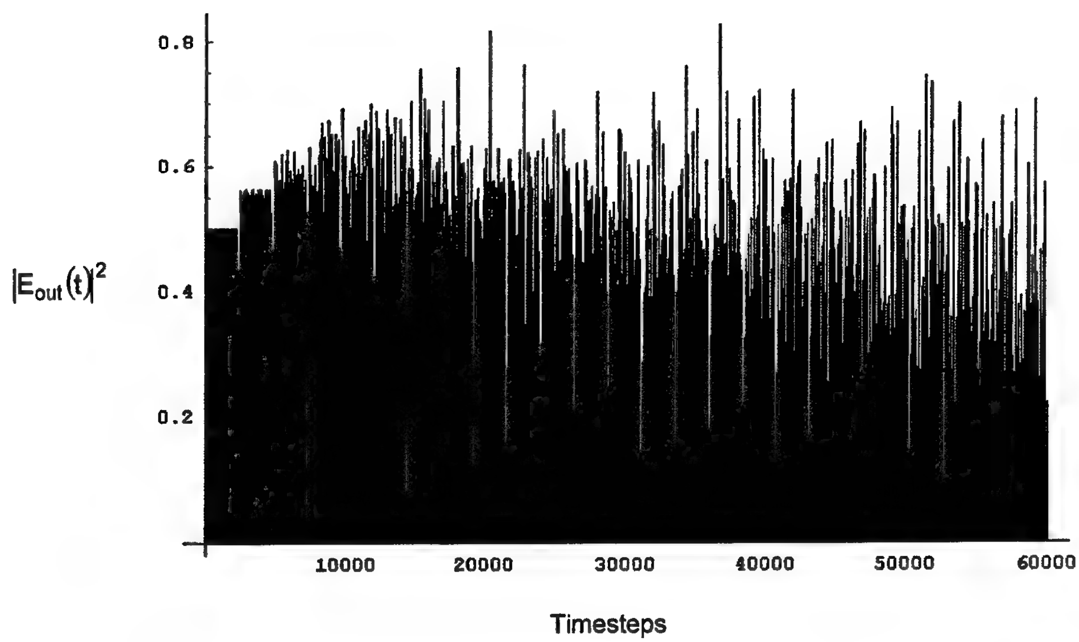


Figure 14: Output of model with 20 dB extinction ratio and open-loop gain of 1.85.

3.4 Overcoming Poor EOM Extinction

References 6 and 17 demonstrated methodologies to suppress the input homodyne noise. The solution to overcome the poor EOM extinction for recirculating-loop PRFM lies in utilising state-of-the-art photonic components. From the simulated results shown in Figures 11 to 13, a suitable extinction ratio of at least 50 dB is required. This is consistent with a signal-to-noise ratio of the first pulse shown in Figure 1. A possible solution is to utilise the low-speed optical MEMS or prism switches, risking deceptive countermeasures against hostile threats not being employed at the earliest possible instance for maximum effect. In addition, the long duration it takes to rearrange the switch would allow the unwanted input homodyne noise to leak through to the recirculating loop.

A new proposal to suppress the input homodyne noise into the recirculating-loop PRFM is illustrated in Figure 15. No optical switch is required. A pulse detector is required to enable the EOM to produce pulsed input into the active recirculating loop. The same signal can be further used to turn the laser diode and an attenuator on and off accordingly, improving the suppression of the unwanted input homodyne noise into the recirculating loop. The solution in Figure 15 is capable of providing more than 50 dB of suppression of the optical carrier. There is no need for specialty photonic components other than COTS devices, which implies cost and engineering benefits.

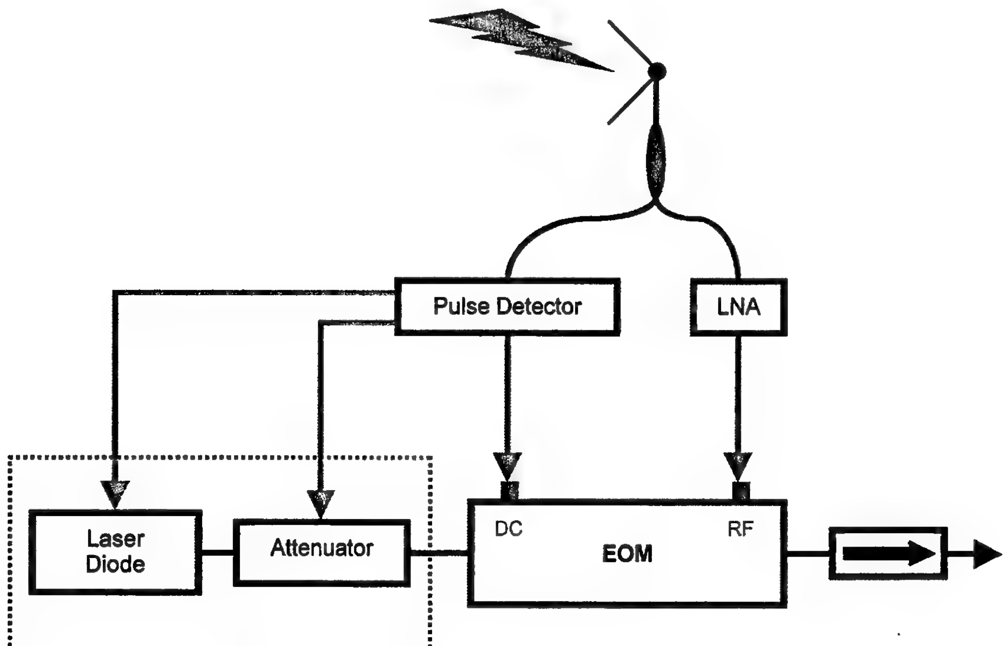


Figure 15: Design of input stage of the active recirculating loop.

The laser diode and attenuator can be in an integrated 14-pin butterfly package. The attenuator takes the form of an integrated external modulator, e.g. a Mach-Zehnder modulator [18] providing up to 14 dB of voltage-controlled attenuation. The laser diode cannot be turned off completely, as it takes time to turn on. Instead, it should be biased at threshold to minimise the turn-on time to maintain the original radar pulsewidth information. Turning the laser on and off from threshold should provide at least 20 dB suppression of the input optical carrier. Assuming a conservative 20 dB extinction from the EOM, these total up to 50 dB of suppression to keep the unwanted input homodyne noise to an acceptable level.

Switching the laser diode directly on and off would chirp the optical output [16]. Chirping would result in problems associated with fibre chromatic dispersion when a large number of recirculations are considered. Another problem would arise if a Doppler frequency-shift were utilised to induce false velocity deception [19]. However, such chirping can be overcome by turning the laser on for a period slightly longer than the radar pulsewidth, and then use both the attenuator and EOM to crop the rising and falling edges of the optical pulse where chirping mostly occurs [16].

3.5 Optical Amplification for the Active Recirculating Loop

The application of standard non-polarisation-maintaining fibre as loop delay needs to address polarisation variation, as highlighted by Reference 6. However, polarisation effects can be minimised by using photonic components that are either polarisation-independent, or at least have low polarisation-dependent losses [6]. The most critical component in the active recirculating loop therefore, is the optical amplifier. There are two technologies for optical amplification, namely the semiconductor optical amplifier (SOA) [6,16,20-21] and erbium-doped fibre amplifier (EDFA) [22]. Table 2 list a summary of characteristics of SOAs and EDFAs [6,16,20-22]. EDFAs have revolutionised long-haul telecommunication systems, but its applicability in recirculating-loop PRFM must be evaluated in comparison with SOAs.

Table 2: A comparison of SOA and EDFA.

	SOA	EDFA
Bandwidth	Both technologies offer similar bandwidth.	
Gain	Both technologies offer typical gain of ~20 dB. EDFAs can be designed to provide higher gain (up to 40 dB).	
Noise	Typical noise figure ~8 dB	Similar typical noise figure. Low-noise designs exhibit noise figures of ~4 dB
Saturation power	~10 dBm	From ~15 up to >30 dBm
Carrier relaxation	Nanoseconds	Milliseconds
Cost	Low	Moderate to high depending on gain and noise figure
Size and weight	Compact 14-pin butterfly package	Bulky. However, planar waveguide technology may offer miniaturisation

In addition to amplifying signals, the optical amplifier is also a source of both homodyne and heterodyne noise in the form of amplified spontaneous emission (ASE). Careful consideration and attention are required to eliminate ASE noise accumulation in the recirculating-loop PRFM.

3.5.1 Heterodyne Noise

The heterodyne noise resulting from ASE accumulation can be minimised by using narrow optical-bandpass-filtering (BPF) [3,6], such as fibre Bragg gratings (FBG) [23]. This is consistent with previous research [3]. The bandwidth of the filter must be wide enough to pass the sidebands representing the electrical modulation frequency of the radar. Filtering of the heterodyne ASE must be given due consideration, as it can accumulate and saturate the optical amplifier, reducing its useful gain [22]. If an electrical spectrum of up to 40 GHz is specified for the recirculating-loop PRFM, the its optical bandwidth would need to be 80 GHz, i.e. ~1 nm. It is still a large bandwidth, which would allow a significant amount of ASE to accumulate. An improved filter is proposed, whose response is depicted in Figure 16.

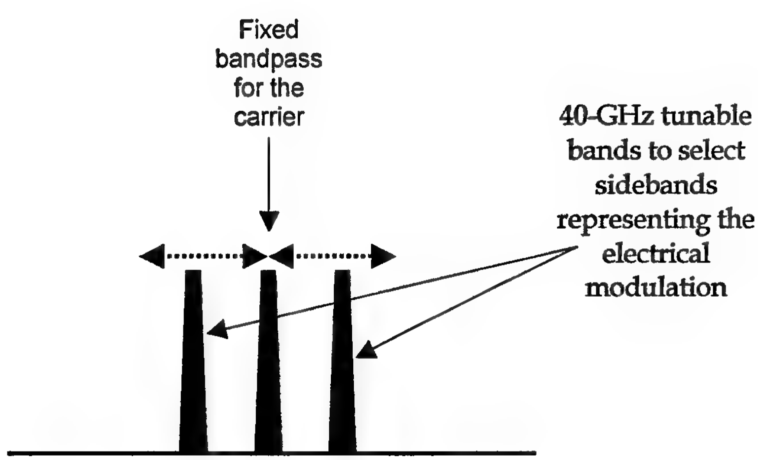


Figure 16: Proposed optical filter response for suppression of heterodyne noise.

The new filter would have three bands, i.e. one fixed band for the optical carrier and two 40 GHz tunable bands to select the sidebands representing electrical modulation up to 40 GHz. This proposed filter could be constructed by:

1. A Fabry-Perot etalon with tunable free-spectral-range. This filter type could provide high finesse for signal selectivity.
2. Two tunable chirped FBGs [23] could be used for the sidebands. However, narrow bandwidth is more difficult to achieve with FBGs.

3.5.2 Homodyne Noise

Optical filtering cannot eliminate homodyne ASE from the optical amplifier, because it is at the same wavelength as the signal of interest. Low-noise optical amplifiers minimise the production of both homodyne and heterodyne ASE, but the noise accumulation problem is not eliminated. References 6 and 17 outline a suitable methodology to suppress the homodyne ASE from the optical amplifier. Nothing can be done when amplifying the stored pulse, but the amplifier should be turned off when not amplifying. In fact, optical amplifiers produce higher amount of ASE when not amplifying. The technique to suppress ASE is known as time-domain filtering or *gating* [6,17]. Gating can also function to erase the stored pulsed from the active recirculating loop, ready to store a new incoming pulse.

From Table 2, an SOA can perform the gating function directly, due to it having a fast carrier relaxation time, i.e. ~5 ns [16]. The EDFA has a carrier relaxation time of ~10 msec [21], which is too long to respond as a gating function as well as amplifying. Application of the EDFA to active recirculating loops would require a separate gating device, which can be an SOA [6].

Figure 17 illustrates designs to suppress both homodyne and heterodyne ASE noise from SOAs and EDFAs for application in the active recirculating loops. The optical amplifier in Figure 2 should be replaced with the circuitry illustrated in Figure 17. In Figure 17(b), the SOA is used to perform the gating function, while the amplification is provided by the EDFA. In this case, the SOA does not need to have much gain. However, when the SOA is used to both amplify and perform the gating function as in Figure 17(a), then an SOA with high gain would be more suitable.

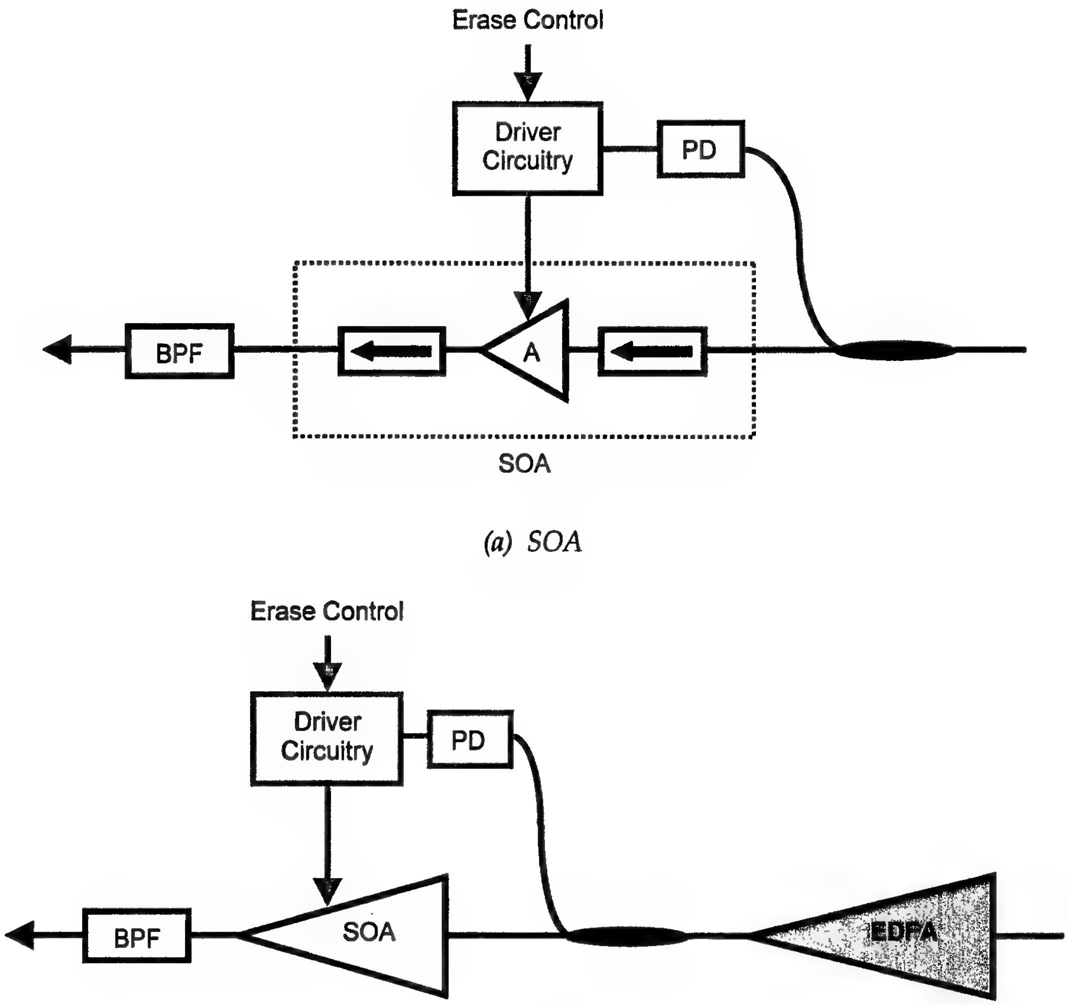
3.6 Loop Delay Requirements

Adam Dickson [6] has demonstrated an active recirculating loop using an SOA and a short loop delay of 80 m, which is equivalent 443 ns. Up to 80 recirculations were obtained for packet-switched digital data. Gating at nanosecond speed was implemented directly with the SOA.

Radar pulsewidths may range from a fraction of a microsecond to several milliseconds [4]. Therefore, the active recirculating loop photonic memory demonstrated in Reference 6 is capable of storing the shortest received radar pulses. Therefore, it can be concluded that recirculating-loop PRFM has a potential resolution of 0.5 μs and storage capability of at least 80 recirculations.

3.6.1 Varying Loop Delay

If the recirculating-loop PRFM operates in an environment in which the received radar pulsewidth does not change, then the loop delay can be fixed according to the known radar pulsewidth.



(a) SOA

(b) EDFA

Figure 17: Design to suppress homodyne and heterodyne ASE noise from optical amplifiers for applications in the recirculating-loop PRFM.

A passive-switchable binary delay memory in Figure 3 could be incorporated, as part of the recirculating loop to improve the operational versatility and flexibility of the recirculating-loop PRFM. The pulse detector at the input stage in Figure 15 could be utilised to rearrange the passive-switchable binary delay network. The following issues relating to optical switches must be carefully considered:

1. Open-loop gain changes due to the varying number of optical switches. Dynamic gain control is needed to maintain closed-loop gain near unity. Relaxation behaviour of the dynamic gain control must be fast to enable a radar pulse to be captured and stored undistorted.
2. High crosstalk or low extinction would worsen the homodyne noise accumulation problem. Signals could propagate through multiple paths and coherently interfere with the actual stored radar pulse.

In an environment in which pulsewidth varies, it is possible to compress all received radar pulses to a fixed pulsewidth before storing them in the recirculating-loop PRFM [3]. The concept of radar pulse compressor and decompressor is depicted in Figure 18. Pulse compression and decompression is achieved by delaying dense wavelength-division multiplexed (DWDM) optical carriers through a chain of FBGs [3]. The DWDM pulse compressor and decompressor is a subject of another research activity and not discussed further in this report.

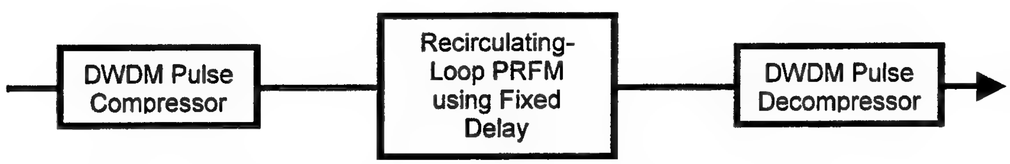


Figure 18: PRFM incorporated into the pulse compressor and decompressor.

3.6.2 Number of Recirculations Required

The number of recirculations required from the recirculating-loop PRFM depends on the duty cycle or factor of the incoming radar signals. The duty cycle is defined as the ratio of the pulsewidth to the pulse repetition interval (PRI).

A duty cycle of 0.0012 or 0.12% has been quoted in Reference 26. If such radar signal were to be stored and replayed continuously with a recirculating-loop PRFM, then the total number of recirculations within the PRI would be up to 1000. This number is high and very difficult to achieve in the first step of the experimental investigation of recirculating-loop PRFM. A number of 100, which corresponds to a duty cycle of 0.01 or 1%, has been suggested as an excellent starting point.

3.7 Multiple-Variable Dynamic Gain Control

Without explaining the functionality of the pulse compressor and decompressor, it suffices to say that there would be optical pulses at multiple wavelengths propagating through the recirculating-loop PRFM as illustrated in Figure 18 [3]. Assuming that the accumulation of both homodyne and heterodyne ASE is controlled, the most critical engineering problem concerning the recirculating-loop PRFM, when incorporated into the pulse compressor and decompressor concept, is the dynamic control of the closed-loop gain. The dynamic gain control problem [28] of the active recirculating loop has become a multiple-variable control problem, i.e. channel power across wavelength range. The closed-loop gain is required to be maintained near unity at multiple wavelengths, otherwise the original radar pulse cannot be reproduced if wavelength-coded pulse amplitudes are unbalanced and their phases are mismatched. This is a wavelength-dependent dynamic gain control problem requiring a fast response time in a fraction of the loop delay.

Wavelength-dependent dynamic gain control is a difficult task. In telecommunication systems, the slow response time of the EDFAs is acceptable, making the dynamic gain control manageable [23-25]. Most dynamic gain control and channel equalisation in recirculating-loop transmission experiments are achieved by knowing exactly how many recirculations are required in advance [12]. If the recirculating-loop PRFM described in this report is to be utilised in range gate pull-off application, then the multiple-variable dynamic gain control needs to have fast response time and it must be applicable for varying number of recirculations.

3.8 Summary

Design issues relating to the recirculating-loop PRFM have been reviewed in reference to previous research [3,6,17]:

1. Limiting input homodyne noise into the recirculating-loop PRFM. Simulation showed that >50 dB suppression of the input optical carrier is required,
2. Suppression of both homodyne and heterodyne noise is highly critical,
3. The choice of optical amplification will influence the design of the recirculating-loop PRFM, and
4. Multiple-variable dynamic gain control must be addressed if the recirculating-loop PRFM is to be incorporated into the pulse compressor and decompressor concept.

Note that the requirement of >50 dB suppression of the input optical carrier is only in reference to the regeneration of the radar pulses using recirculating-loop PRFM. The effect of homodyne noise on the threat seduction process has not been analysed.

4. Conclusions

Passive-switchable photonic radio-frequency (RF) memory (PRFM) requires an optical switching technology that has low insertion loss, fast switching speed and low crosstalk. However, a review of commercial-off-the-shelf (COTS) technologies shows that there is no single technology that can meet all of the desired characteristics.

Research into a photonic buffer for packet-switched data by Adam Dickson [6] has many similarities to PRFM. It is therefore the most authoritative reference on the subject. Recirculating-loop PRFM requires a systematic approach, addressing all design issues at once, in order to make it operational. Erbium-doped fibre amplifiers (EDFAs) might not be applicable to the active recirculating loop. Semiconductor optical amplifiers (SOAs) provide simultaneously both the gain and switching speed required for fast noise and gain control. The major design issues of the active recirculating loop are summarised below:

1. Limiting input homodyne noise into the recirculating-loop PRFM. Simulation shows that >50 dB suppression of the input optical carrier is required,
2. Suppression of both homodyne and heterodyne noise is highly critical,
3. The choice of optical amplification will influence the design of the recirculating-loop PRFM, and
4. Multiple-variable dynamic gain control must be addressed if the recirculating-loop PRFM is to be incorporated into the pulse compressor and decompressor concept.

Multiple-variable dynamic gain control of optical amplifiers is a difficult engineering task, which warrants dedicated research resources. It will have far reaching applications wherever dense wavelength-division multiplexing is deployed, e.g. recirculating-loop PRFM as a defence application and channel equalisation in all-optical network in telecommunications.

5. Recommendations

Research on implementing single-wavelength operation of the recirculating-loop photonic radio-frequency (RF) memory (PRFM) has been re-initiated. One recommendation is to focus on the PRFM as a whole system of components working together, rather than focusing on individual components. Simple solutions with inexpensive commercial-off-the shelf (COTS) components are intuitively possible. High-speed electronics expertise is essential.

Four areas to target in the experimental investigation of recirculating-loop PRFM are recommended:

1. Simulation shows that >50-dB suppression of the input optical carrier is required to suppress homodyne noise problem. Techniques to obtain such high extinction are required. A single external modulator would only provide at best 25 dB. A solution proposed in this report, i.e. using a laser with an integrated modulator and an additional external modulator, is one possible technique.
2. Suppression of heterodyne noise is also highly critical. Narrowband optical bandpass filtering would only do a partial job suppressing the heterodyne noise. A special three-band optical filter proposed in this report must be investigated. Gating must be implemented to further eliminate heterodyne noise.
3. The choice of optical amplification will influence the design of the recirculating-loop PRFM. Both semiconductor optical amplifiers and erbium-doped fibre amplifiers must be investigated to determine the more suitable candidate for application in recirculating-loop PRFM.
4. Dynamic gain control in multiple-wavelength recirculating-loop PRFM should also be attempted.

6. Acknowledgement

Many thanks to Dr. David Hunter and Dr. Anthony Lindsay of Defence Science and Technology Organisation and Ms. Anna Hurt of Tenix Defence Systems Pty. Ltd. for useful discussions on the active recirculating loop. Mr. Daniel Borg provided information related to the commercial optical switches.

Special thanks to Dr. Thas Nirmalathas, Dr. Yang Jing Wen, Dr. Manik Attygalle and Dr. Bo-Hun (Adam) Choi of the University of Melbourne for fruitful discussions on multiple-variable dynamic gain control of erbium-doped fibre amplifiers.

7. References

[1] S.T.Winnall, "Microwave photonic receivers for electronic warfare applications", *PhD Thesis at RMIT University*, 2001

[2] D.B.Hunter, "Microwave photonic signal processing using fibre Bragg grating structures", *PhD Thesis at the University of Sydney*, 1999

[3] D.B.Hunter, "Technical Review November 2001", Electronic Warfare & Radar Division, Defence Science and Technology Organisation

[4] G.W.Stimson, "Introduction to Airborne Radar", SciTech Publishing Inc., 1998

[5] M.Manka of Tenix Defence Systems Pty. Ltd., a presentation to staff of the Electronic Warfare & Radar Division, September 2002

[6] A.M.Dickson, "Optical fibre-loop buffers", *PhD Thesis at the University of Melbourne*, 1996

[7] D.Borg, Electronic Warfare & Radar Division, Defence Science and Technology Organisation

[8] http://www.diconfiber.com

[9] http://www.aeroflex.com

[10] http://www.zenastra.com

[11] http://www.jdsu.com

[12] Private communications with Thas Nirmalathas, Yang Jing Wen, Manik Attygalle and Bo-Hun (Adam) Choi, Photonics Research Laboratory, University of Melbourne

[13] L.V.T.Nguyen, "Modelling wavelength-dependence of optical gain and ultrafast behaviour in semiconductor lasers", *PhD Thesis at the University of Melbourne*, 1997

[14] http://www.vpisystems.com

[15] L.V.T.Nguyen, "Mode-partition noise in semiconductor lasers", *DSTO Research Report DSTO-RR-0244*, Defence Science and Technology Organisation, 2002

[16] G.P.Agrawal and N.K.Dutta, "Long-wavelength semiconductor lasers", Van Nostrand Reinhold

[17] E.Dietrich, G.Groβkopf, L Küller, R.Ludwig, W.Pieper and H.G.Weber, "BER measurements in random access fibre loop optical memory", *Electronics Letters*, **27**, pp. 1585-1586, 1991

[18] "LCM155W-20A 2.5 Gb/s InP MZ modulator with DWDM laser", http://www.nortelnetworks.com

[19] S.T.Winnall, A.C.Lindsay and G.A.Knight, "A wide-band microwave photonic phase and frequency shifter", *IEEE Transactions on Microwave Theory and Techniques*, **45**, pp. 1003-1006, 1997

[20] Application Note "Semiconductor optical amplifier (SOA)", http://www.jdsu.com

[21] "CQF874 Series polarisation independent semiconductor optical amplifier with isolators", http://www.jdsu.com

[22] E.Snitzer, "Erbium-doped fibre amplifier - Fundamentals and technology", Academic Press, 1999

[23] R.Kashyap, "Fiber Bragg gratings", Academic Press, 1999

[24] H.Hou, "Dynamic gain equalization using all-fiber acousto-optical tunable filter (AOTF) technology", *Application Note*, Novera Optics, Inc., http://www.noveraoptics.com, 2001

[25] C.Konishi, T.Yoshida, S.Hamada, K.Asahi and S.Fujita, "Dynamic gain-controlled erbium-doped fiber amplifier repeater for WDM network", *OFC'97 Technical Digest*, 1997

[25] K.Motoshima, N.Suzuki, K.Shimizu, K.Kasahara, T.Kitayama and T.Yasui, "A channel-number insensitive erbium-doped fiber amplifier with automatic gain and power regulation function", *IEEE Journal of Lightwave Technology*, **19**, pp. 1759-1767, 2001

[26] H.Zmuda and E.N.Toughlian, "Photonic aspects of modern radar", Artech House, 1994

[27] Communications with Dr. Anthony Lindsay of the Electronic Warfare & Radar Division, Defence Science & Technology Organisation

[28] J.Hecht, "Many roads lead to dynamic gain equalisation in optical networks", *Laser Focus World*, pp. 107-111, October 2002

DISTRIBUTION LIST

Photonic Radio Frequency Memory – Design Issues and Possible Solutions

Linh V T Nguyen

AUSTRALIA

DEFENCE ORGANISATION	No. of Copies
Task Sponsor, DGSPD	1
S&T Program	
Chief Defence Scientist	shared copy
FAS Science Policy	
AS Science Corporate Management	
Director General Science Policy Development	
Counsellor Defence Science, London	Doc Data Sheet
Counsellor Defence Science, Washington	Doc Data Sheet
Scientific Adviser Joint	1
Navy Scientific Adviser	Doc Data Sheet
Scientific Adviser - Army	Doc Data Sheet
Air Force Scientific Adviser	Doc Data Sheet
Scientific Adviser to the DMO M&A	Doc Data Sheet
Scientific Adviser to the DMO ELL	Doc Data Sheet
Director of Trials	1
JEWOSU, Squadron Leader Mark Riley	1
Systems Sciences Laboratory	
EWSTIS (soft copy for accession to EWSTIS Web site)	1
Chief, Electronic Warfare and Radar Division	Doc Data Sheet
Research Leader, EW Systems	Doc Data Sheet
Research Leader, EO Electronic Warfare	Doc Data Sheet
Research Leader, Microwave Radar	Doc Data Sheet
Head, EO Technologies	Doc Data Sheet
Dr David Hunter, EWRD,	Doc Data Sheet
Dr Tim Priest, EWRD,	Doc Data Sheet
Dr Kamal Gupta, EWRD,	Doc Data Sheet
Mr Daniel Borg, EWRD,	Doc Data Sheet
Linh V. T. Nguyen, EWRD,	2
DSTO Library and Archives	
Library Edinburgh	1 +Doc Data Sheet
Australian Archives	1
Capability Systems Division	
Director General Maritime Development	Doc Data Sheet
Director General Aerospace Development	Doc Data Sheet
Director General Information Capability Development	Doc Data Sheet
Office of the Chief Information Officer	
Deputy CIO	Doc Data Sheet
Director General Information Policy and Plans	Doc Data Sheet
AS Information Structures and Futures	Doc Data Sheet

AS Information Architecture and Management	Doc Data Sheet
Director General Australian Defence Simulation Office	Doc Data Sheet

Strategy Group

Director General Military Strategy	Doc Data Sheet
Director General Preparedness	Doc Data Sheet

HQAST

SO (Science) (ASJIC)	Doc Data Sheet

Navy

SO (SCIENCE), COMAUSNAVSURFGRP, NSW & Dist List	Doc Data Sheet
Director General Navy Capability, Performance and Plans, Navy Headquarters	Doc Data Sheet
Director General Navy Strategic Policy and Futures, Navy Headquarters	Doc Data Sheet

Army

ABCA National Standardisation Officer, Land Warfare Development Sector, Puckapunyal	e-mailed Doc Data Sheet
SO (Science), Deployable Joint Force Headquarters (DJFHQ) (L), Enoggera QLD	Doc Data Sheet
SO (Science) - Land Headquarters (LHQ), Victoria Barracks NSW	Doc Data Sheet & Exec Summary

Intelligence Program

DGSTA Defence Intelligence Organisation	1
Manager, Information Centre, Defence Intelligence Organisation	1
Assistant Secretary Corporate, Defence Imagery and Geospatial Organisation	Doc Data Sheet

Defence Materiel Organisation

Head Airborne Surveillance and Control	Doc Data Sheet
Head Aerospace Systems Division	Doc Data Sheet
Head Electronic Systems Division	Doc Data Sheet
Head Maritime Systems Division	Doc Data Sheet
Head Land Systems Division	Doc Data Sheet
Head Industry Division	Doc Data Sheet
Chief Joint Logistics Command	Doc Data Sheet
Management Information Systems Division	Doc Data Sheet
Head Materiel Finance	Doc Data Sheet

Defence Libraries

Library Manager, DLS-Canberra	Doc Data Sheet
Library Manager, DLS - Sydney West	Doc Data Sheet

OTHER ORGANISATIONS

National Library of Australia	1
NASA (Canberra)	1
Library of New South Wales	1

UNIVERSITIES AND COLLEGES

Australian Defence Force Academy	
Library	1
Head of Aerospace and Mechanical Engineering	1

Serials Section (M list), Deakin University Library, Geelong, VIC	1
Hargrave Library, Monash University	Doc Data Sheet
Librarian, Flinders University	1

OUTSIDE AUSTRALIA

INTERNATIONAL DEFENCE INFORMATION CENTRES

US Defense Technical Information Center	2
UK Defence Research Information Centre	2
Canada Defence Scientific Information Service	(pdf format) 1
NZ Defence Information Centre	1

ABSTRACTING AND INFORMATION ORGANISATIONS

Library, Chemical Abstracts Reference Service	1
Engineering Societies Library, US	1
Materials Information, Cambridge Scientific Abstracts, US	1
Documents Librarian, The Center for Research Libraries, US	1

SPARES	5
Total number of copies:	**33**

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
DOCUMENT CONTROL DATA

1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)
UNCLASSIFIED

2. TITLE	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION)
Photonic Radio Frequency Memory – Design Issues and Possible Solutions	Document (U) Title (U) Abstract (U)

4. AUTHOR(S)	5. CORPORATE AUTHOR
Linh V T Nguyen	Systems Sciences Laboratory PO Box 1500 Edinburgh South Australia 5111 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TR-1491	AR-012-890	Technical Report	December 2003

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
E 9505-23-228 1	LRR 02/178	DGSPD	30	26

13. URL on the World Wide	14. RELEASE AUTHORITY
http://www.dsto.defence.gov.au/corporate/reports/DSTO-TR-1491.pdf	Chief, Electronic Warfare & Radar Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, EDINBURGH, SA 5111

16. DELIBERATE ANNOUNCEMENT

No Limitations

17. CITATION IN OTHER DOCUMENTS Yes

18. DEFTEST DESCRIPTORS

Electronic warfare
Photonics
Radar signals
Radiofrequency interference

19. ABSTRACT

False target generation, range and velocity gate pull-off are Electronic Attack (EA) techniques in which received radar pulses are stored, then read out and re-transmitted back to the source radar after the desired length of time. The memory can be either a recirculating delay line or a digital radio-frequency (RF) memory (DRFM). The DRFM stores a digitised sample of each received pulse, which can provide high fidelity if the analogue-digital conversion process has sufficient dynamic range. The speed of digital signal processing and memory plays a critical role in DRFM design. The analogue-digital conversion process and bit-rate limit the range of frequencies that DRFMs can cover.

Photonics is currently being investigated to implement EA techniques such as false target generation, range and velocity gate pull-off. To fully take advantage of the unique benefits offered by photonics to implement EA techniques, the development of photonic RF memory (PRFM) is required. PRFM can potentially cover frequencies from near DC to 110 GHz, which are of interest in Electronic Warfare (EW). Photonic technology offers the opportunity for high fidelity signal storage without the use of down-conversion or analogue-to-digital converters. In this report, design issues and possible solutions of PRFM are discussed to assist with the ongoing experimental investigation.